NASA-CR-194424

#5 Technical Report

on

Two Color Holographic Interferometry for Microgravity Application

Contract No. NAS8-39402
DCN: 1-2-ES-44818

Prepared for

COTR: William K. Witherow/ES74
NASA Marshall Space Flight Center, Alabama

Period from April 1, 1993 to October 1, 1993

Prepared by

James D. Trolinger, Ph.D.
Principal Investigator
MetroLaser
18006 Skypark Circle #108
Irvine, CA 92714-6428
(714) 553-0688

TNA05T5

TWO COLOR HOLOGRAPHIC INTERFEROMETRY FOR MICROGRAVITY APPLICATION

OBJECTIVE

Holographic interferometry is a primary candidate for the measurement of temperature and concentration in various crystal growth experiments destined for space. The method measures refractive index changes in the experiment test cell. A refractive index change can be caused by concentration changes, temperature changes, or a combination of temperature and concentration changes. If the refractive index changes are caused by temperature and concentration changes occurring simultaneously in the experiment test cell, the contributions by the two effects cannot be separated by conventional measurement methods. By using two wavelengths, two independent interferograms can be produced from the reconstruction of the hologram. The two interferograms will be different due to dispersion properties of fluid materials. These differences provide the additional information that allows the separation of simultaneously occurring temperature and concentration gradients. There is no other technique available that can provide this type of information.

The primary objectives of this effort are to experimentally verify the mathematical theory of two color holographic interferometry and to determine the practical value of this technique for space application.

To achieve these objectives, the accuracy and sensitivity of the technique must be determined for geometry's and materials that are relevant to the Materials Processing in the Space program of NASA. This will be achieved through the use of a specially designed two-color holographic interferometry breadboard optical system. In addition to experiments to achieve the primary goals, the breadboard will also provide inputs to the design of an optimum space flight system.

WORK COMPLETED BEFORE THIS PERIOD

Summary

During prior work periods, three experiment series were completed in the Space Processing Laboratory at MSFC in a cooperative effort with NASA, UAH, and MetroLaser. MetroLaser supported the experiments on site during all three series and provided off site assistance with supporting calculations and design. The experiments were conducted with existing NASA hardware and with complementary hardware supplied by MetroLaser. Experiments verified that the required sensitivity could be met when using two color holographic interferometry. The experiments also provided important experience and input to the design of the optical TCHI breadboard.

Calibration measurements demonstrated that a resolution of conservatively $\lambda/100$ or better could be achieved and that the lower limit was a result of vibration of the optical elements. A significant amount of the vibration was caused by acoustics. It was found that considerable improvement in the system function was possible early in the morning and late in the evening when activities in the building were reduced.

The second test series began during the week of 25 January, 1993. The data confirmed that all systems were working properly and that the two color method could be tested in the apparatus. The information was used to refine the hardware and the test procedure. The experiments laid the ground work for a third test series which was conducted the first week of March 1993. Preliminary quantitative results compared well with calculations and expected results.

The design of the MSFC breadboard was completed and tested in the preliminary experiments. The design included an analysis of the phase shift introduced by a tilted plate as a function of angle including the sensitivity of the device as a function of thickness and angle. The analysis showed that to achieve the sensitivities required, we needed to use a thin plate starting at about a five degree tilt angle. Curves for all of the relevant angles, plate thicknesses and starting angles were plotted and provided. The design for the space flight system will be a fiber optic phase shifter to be compatible with the compact design that uses fiber optics.

A test cell design was built which would allow both constant and gradient conditions to be set up for temperature and concentration in the test fluid. This cell was tested during the second series of tests at MSFC and the results of the experiments were used to improve the cell design. The test cell was sent back to MetroLaser where these improvements were implemented and checked out.

Discussion

Experimental Program

Figure 1 schematically shows the experimental setup used during the third set of experiments conducted in the Space Processing Optical Laboratory. The system is constructed on a vibrationally isolated granite table. The components are damped by modeler's clay pressed around the bases. The room air currents are mitigated with a Plexiglas housing that covers all of the optics.

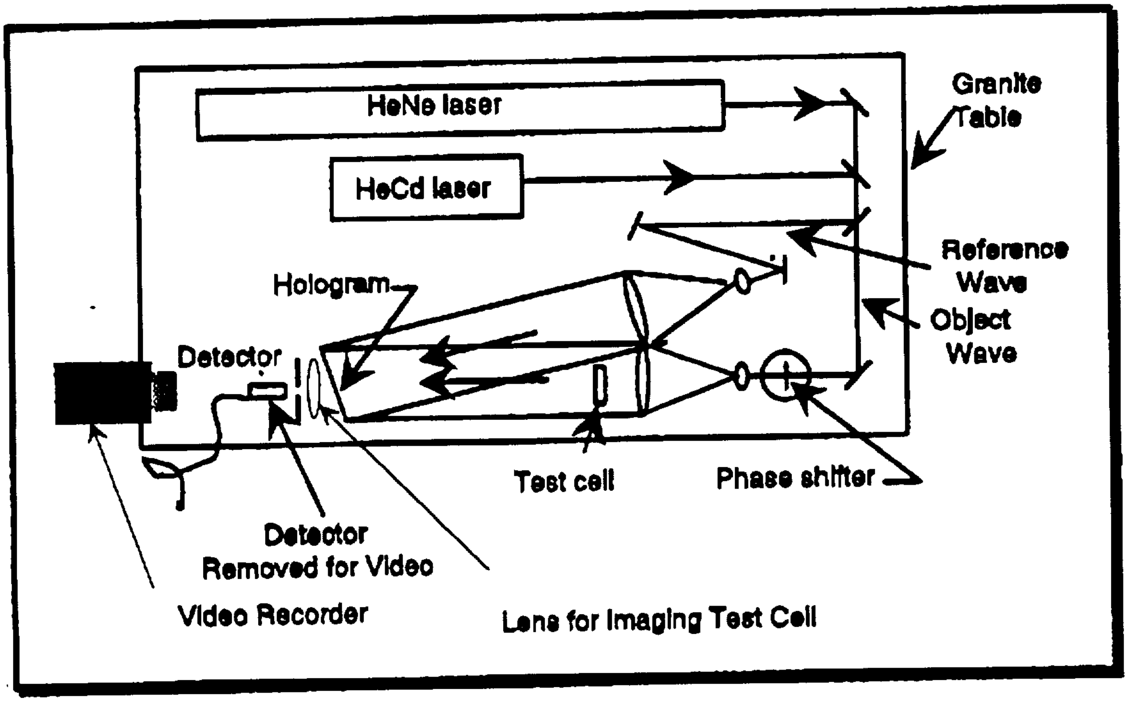

Figure 1. Experimental Set-up for Two Color Holographic Interferometry

Holograms of the cell were recorded simultaneously with the HeNe and HeCd lasers. A hologram was produced, developed and then returned precisely to its original position. The reconstructed wave front and the real wave front were mixed to form a real time holographic interferogram of the solution in the test cell. (Figure 2).

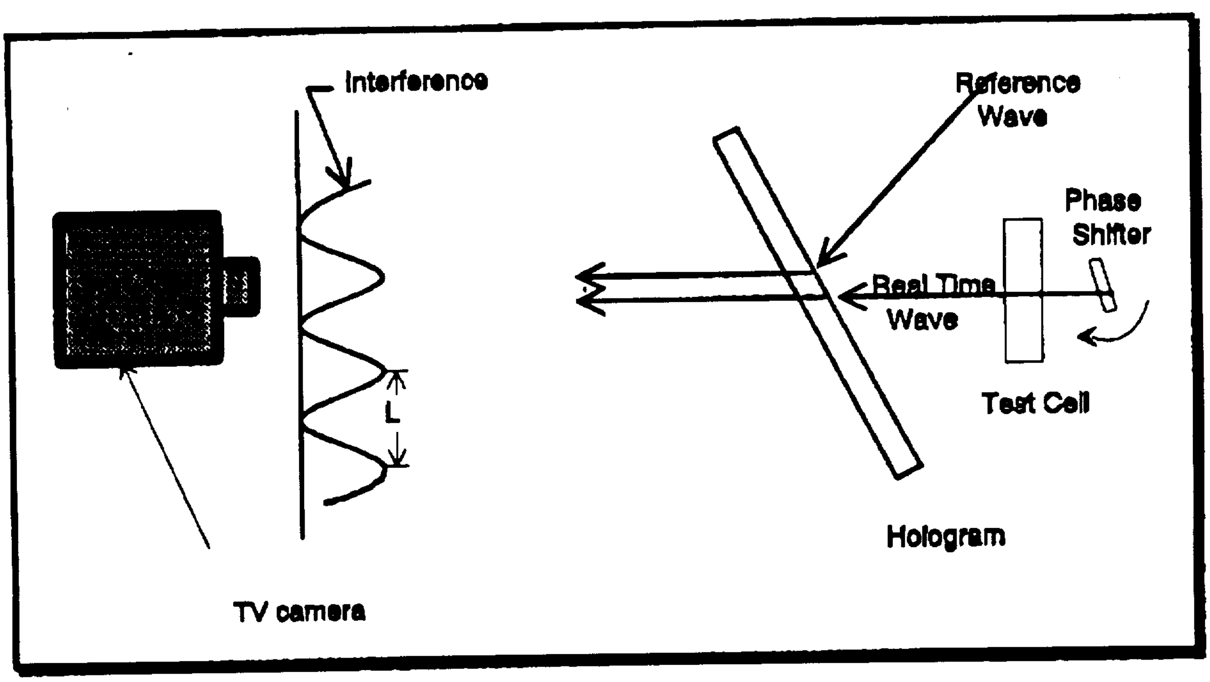

Figure 2. Formation of the Real Time Holographic Interferogram

The phase shifter was rotated by a rotary mount which was driven by a Physik Instrument GmB type M-2240-398 translator which was computer controlled. Using this translator with previous calibration and computations we could demonstrate a linear introduction of phase shift with a resolution better than $\lambda/10{,}000$; considerably better than was needed for the experiment. Typically 30,000 to 40,000 steps of the translator would produce a 360° degree phase shift, depending on the wavelength being used. The phase shifter was set at an initial angle of about 10 degrees. Our previous computations showed that the phase shift should be linear with angle over at least a 360° degree phase shift.

Concentration Changes

With pure water in the cell we estimate that since dn/dt = $10^{-4}/^{\circ}C$ we should see a path length change of :

HeNe 1/.633=1.6 fringes per °C and,

HeCd 1/.442=2.26 fringes per °C

We did not expect this to change much with concentration at small concentrations.

For this cell, our previously reported concentration verses path length calculations showed that a one percent change in sucrose concentration will cause an optical path length change, ΔP of 22 λ. Consequently,

$0.1\%\ \Delta C \Rightarrow \Delta P = 2.2\lambda.$

$0.01\%\ \Delta C \Rightarrow \Delta P = 0.22\lambda.$

$0.02\%\ \Delta C \Rightarrow \Delta P = 0.44\lambda.$

For this experiment we chose concentration and temperature value changes that would lead to about $\lambda/2$ changes in the path length or about 180 degrees phase shift. This would allow us to easily observe the fringe shifts on a CCTV system which we used to record the overall phase field.

Figure 3 shows the test cell geometry. A solution of one gm sucrose per 500 cc water was mixed. Using a pipette, 1.6 cc of liquid (or 10% of the 16 cc cell volume) was removed from the cell which initially contained distilled water and was replaced with the one part per 500 sucrose solution. This should result in a change of 0.02% concentration and would be expected to lead to a change in path length of 0.44λ. A repetition of the process should about double this to 0.88λ.

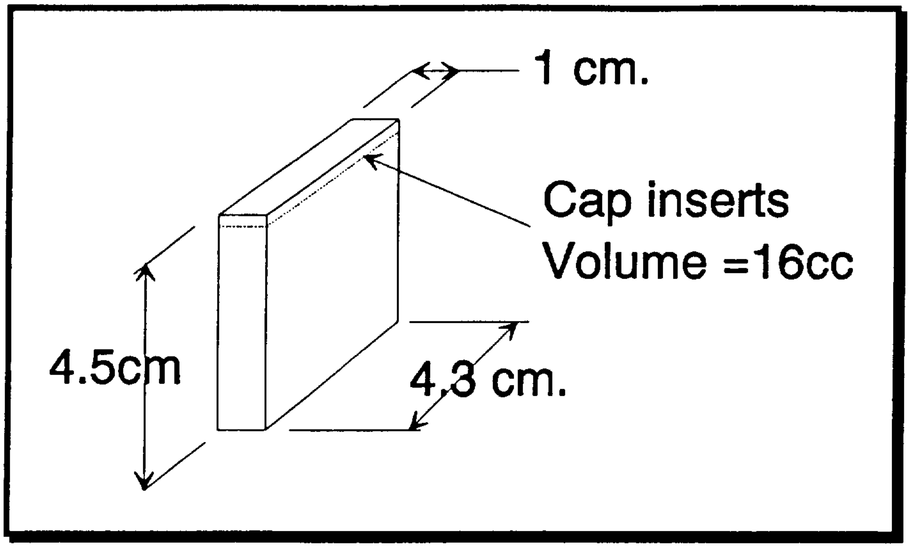

Figure 3. Quartz Test Cell Geometry

The phase shifter was programmed to shift the phase four times, giving five intensities, with a ten second delay at each new phase to allow the fringes to stabilize and allow a VCR recording (see Figure 2) to be made. Then the phase stepper was returned in four steps to its original position. The video system was refined over the last experiment series by optically coupling the reconstructed image directly into the TV camera. This gave ample energy, which we did not have before, gave an improved image, and allowed us to focus on the cell. The lens allowed us to fill the TV format.

The same computer controlled the temperature, displayed the value of temperature at the location of six thermocouples, and controlled the phase shifting motor. The computer can record and save temperature values directly; however, recordings of temperature were done by hand in these experiments. For most of the experiments only the thermocouples mounted in the top and bottom of the cell were monitored. This was done so that the thermocouples would not block part of the field of view.

The test cell operated extremely well during the test series and was therefore left in place at MSFC in the event we decide to run additional test series there before the breadboard is completed. The data will be discussed further in the next report.

Work was initiated on the instruction manual for the software and hardware, included as an appendix.

Breadboard Design

The breadboard system is illustrated in **Figure 4**, and is discussed at length in prior reports. The construction and testing to the breadboard system is discussed under the section on work performed during the current work period.

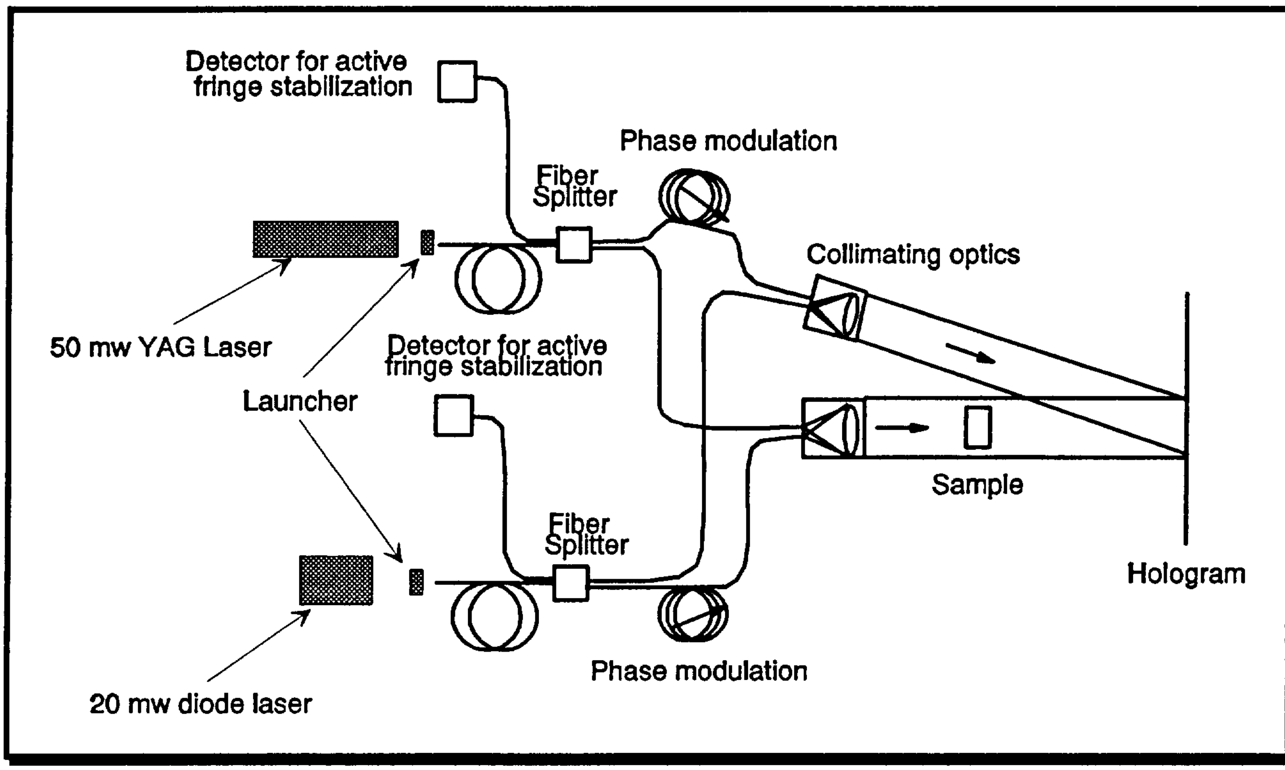

Figure 4. Space Flight Breadboard

Test Cell Design

Meetings were held at MSFC and at MetroLaser to discuss the test cell design requirements. We arrived at an agreement for preliminary test cell requirements during the meetings and proceeded with the design.

1. The test cell design was completed during the month of October 1992. The design incorporates all of the features agreed to in earlier meetings. The cell will support programmable constant temperature and concentration measurements, temperature and concentration gradients, and incorporates thermoelectric heating and cooling, water cooling, and thermocouples for temperature measurement.

2. Cell components were acquired and/or built during the months of November and December, 1992. The cell was assembled and checked out during the

month of January, 1993. A computer program was written for temperature control and monitoring.

3. The cell was installed in the SSL TCHI breadboard and checked out.

The following experimental test conditions are supported by the test cell(s):

1. A solution with an optical path distance of precisely 1 centimeter having constant (in space and time), known, adjustable temperature and concentration with the ability to change concentration and temperature of the solution.

2. A solution with an optical path distance of precisely 1 centimeter with constant temperature (in space and time) and a known concentration gradient.

3. A solution with an optical path distance of precisely 1 centimeter with constant (in space and time) concentration distribution and a known temperature gradient.

The ranges and accuracy of temperature and concentration are representative of typical space crystal growth conditions.

With the first set of conditions we can show the capability of TCHI to measure changes in temperature and concentration independently. This will establish the capabilities and limits of TCHI in separating temperature and concentration.

With the second set of conditions we can show the capability of TCHI to measure distributions of temperature and concentration.

A schematic of the test chamber developed to experimentally evaluate the use of two color holography to simultaneously measure both temperature and concentration gradients is shown in **Figure 5**. The test liquid (a sucrose solution in the experimentation done at MSFC) is contained in a quartz cell in the center of the chamber. The cell consists of quartz faces on four sides and the bottom, the top being capped by an aluminum cap. To control the temperature of the test liquid, or to introduce a temperature gradient, thermo-electric's are located above and below the quartz cell. The top set of thermo-electric's is attached to an aluminum block which is in direct contact with the test liquid via the open top of the quartz cell. The bottom thermo-electric's are attached to a copper block upon which the cell sits. A thin layer of mineral oil is placed between the copper block and the quartz cell to assure good thermal contact.

The quartz cell and thermo-electric's are mounted inside a copper enclosure with thick side walls and two open faces to allow optical access to the test liquid. This enclosure acts as a heat sink and, due to the high thermal conductivity of the copper, tends to maintain an even temperature distribution throughout. To insulate the copper enclosure from any ambient temperature variations, it is contained inside a second enclosure made of polypropylene. Glass windows are placed on the front and rear faces of the outer enclosure to again permit optical access and to insulate the inner cell with an air layer. The copper enclosure sits on the polypropylene enclosure and is secured by contact at the top corners. An air gap between the two enclosures acts to further insulate the copper enclosure from outside ambient conditions.

An access port in top of the outside enclosure allowed an elongated fixture containing four thermocouples, mounted at different vertical positions, to be placed into the test liquid. This allows the temperature of the test fluid to be monitored at different locations throughout the test cell. In this way any induced temperature gradients can be measured directly to confirm the holographic results. They can also act as feedback to maintain an isothermal condition using the thermo-electric's. The monitoring of these thermocouples along with the operation of the two sets of thermo-electric's is under computer control using software developed at MetroLaser for this project. Layers of different solute concentrations can also be introduced using a pipette via the same access port. In this way both a concentration and a temperature gradient of known value can be produced inside the cell simultaneously.

An alternate method for generating more accurate gradients, produced by the Jule Corporation, was evaluated and considered unnecessary at the present time.

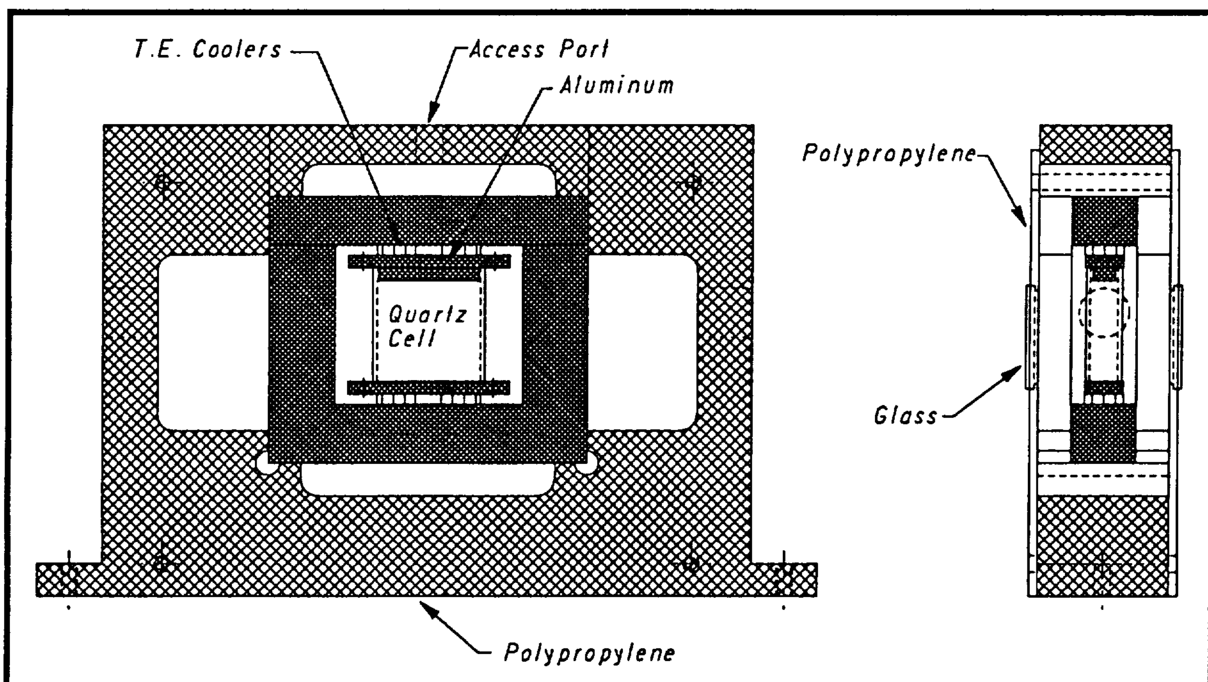

Figure 5. Test chamber developed to confirm the two color holography technique experimentally. The chamber consists of the inner quartz cell, thermo-electric's, and two enclosures (made of copper and polypropylene).

Two types of cell temperature control are possible with the cell, water bath and thermoelectric. The advantage of thermoelectric coolers/heaters are that 1) they contain no moving parts and therefore introduce no vibrations into the system and 2) are small, lightweight and respond quickly to current inputs. The main disadvantage to such a system is that they have large thermal expansion coefficients and must be mechanically de-coupled from the test cell. Constant temperature water baths that may be used to cool or heat the cell are commercially available; however, the circulating water will introduce vibrations that may upset the holographic measurements. Additionally, the degree of accuracy required in both the control and monitoring of the test solution temperature (0.1°C) presents a challenge for both methods of temperature control.

Five thermocouples monitor the temperature in the solution and at the top and bottom of the cell. The outputs from these are displayed on the monitor of the computer which controls the thermocouples and heaters.

WORK PERFORMED DURING THIS PERIOD:

Summary

1. Fourth experimental series was run at MSFC in July to obtain improved two color holography videos for data reduction.

2. Fiber optic breadboard hardware ordered, recieved, assembled, and initial system alignments and checkouts done.

3. Data reduction software development partially completed.

Discussion

Breadboard Design

The hardware for the fiber optic breadboard design of **Figure 4** was specified, ordered, and assembled. A list of the major components in the system are found in **Table 1** along with a list of vendors and the final cost upon placement of the purchase orders. While the cost of the doubled YAG was a major expenditure, the final cost was actually negotiated down $3,000 from the initial vendor asking price of $16,000.

Table 1
Cost of major components in the fiber optic breadboard.

Item	Vendor	Cost
Doubled YAG laser	ADLAS, Inc.	$13,100
Diode laser	LaserMax	1,180
Diode laser temp. controller	Light Control Instr., Inc.	1,810
Fiber launchers (2)	Oz Optics Ltd.	750
Fiber optic system	Canadian Instr.	4,240
Collimation lenses (2)	Jeager	400
	Total:	$21,480

The diode laser "system" actually required some minimal integration of the diode laser, the thermoelectric controllers and mounts, and the electronic temperature controller which drives the thermoelectrics. Both lasers have also been checked out with the fiber launchers from Oz Optics and the rotation of the launcher to each laser was optimized to match the polarizations of the lasers to the single mode, polarization maintaining fibers. Prior to this alignment procedure, the axial location of the lens in the fiber launcher also had to be adjusted to optimize the launching efficiency. While this initial alignment took some time, the launcher has since required little or no adjustment to maintain optimum output, even when the system has been left sitting for days without use.

The fiber optic system constitutes the heart of the breadboard design and is represented schematically in **Figure 6**. The system consists of four FCPC connectors, two fiber optic couplers and a special output coupler. One of the two FCPC connectors going into each of the couplers is connected to each of the two lasers. The fibers into and out of each coupler are single mode fibers which are optimized, along with the coupler itself, for the wavelength of the laser to be used ($\lambda = 532$ and 680 nm). Each coupler was designed to produce a 50/50 output into the two fibers on the output side of the coupler for the design wavelength. The other input into the coupler will act as a feedback for either stabilizing or controlling the phase of the output from the fiber (this technique has been described in detail in a past report). One fiber from each of the couplers is cemented together in the special output coupler. This special arrangement allows the core of each of the two fibers to be located within approximately 10 μm of one another, thereby virtually eliminating the alignment errors between the two colors in each output leg.

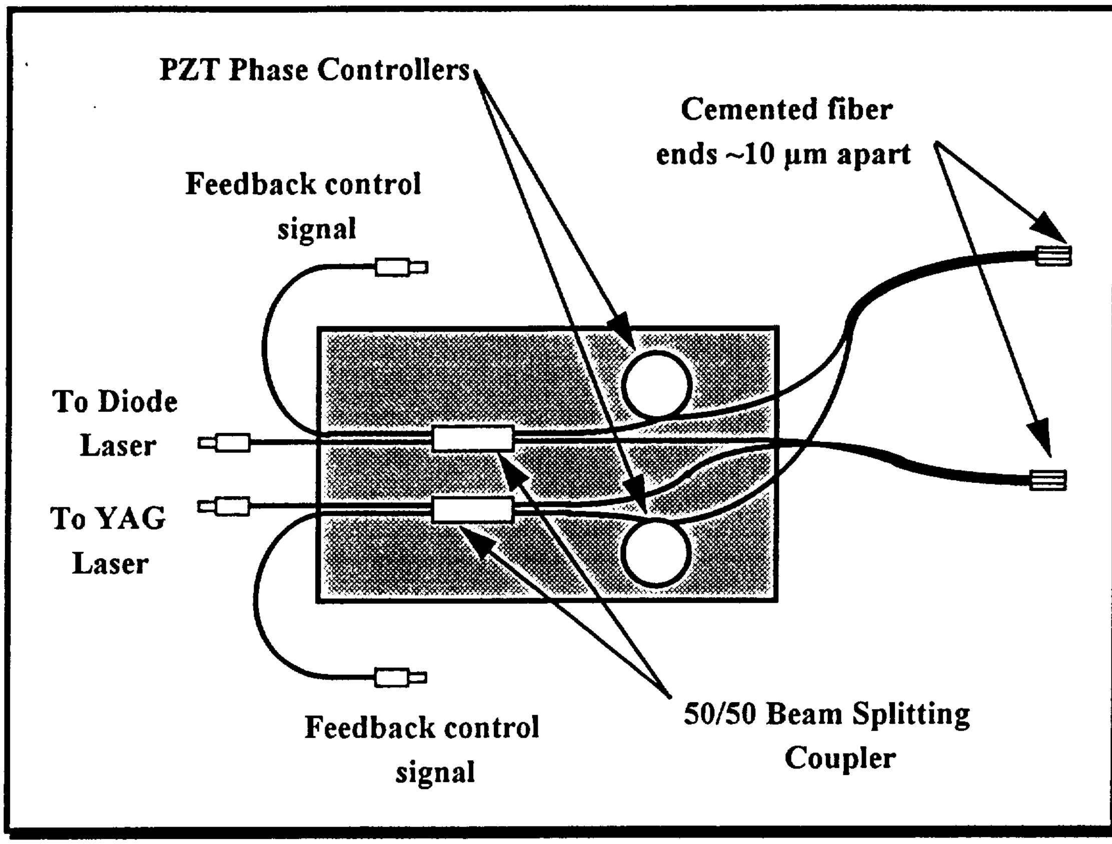

Figure 6. Schematic of the fiber optic system manufactured by Canadian Instruments.

Once aligned, the output characteristics from each laser were determined. The results of this testing are shown in Table 2. The uneven split of the power out of the diode laser between the output legs shown in this table appears to be a result of improper design by the vendor of the coupler to produce a 50/50 split. The vendor did not actually have a laser with the 680 nm wavelength of the diode laser to be used in the system, but presumed he could extrapolate the performance at 680 nm based on the HeNe laser ($\lambda = 633$ nm) he had in-house. It appears his extrapolation was either invalid or improperly calculated. Due to the long lead time involved in fabrication and subsequent modification of this system, it was decided to live with the current system which seemed to otherwise perform acceptably. The 3-to-1 split in the power might even prove beneficial for holography, where a stronger reference beam can actually improve some aspects of the hologram.

Table 2
Experimentally measured performance of the fiber optic breadboard.

Laser	Rated Output	Measured Output	Extinction Ratio	Power Efficiency at Fiber Output Leg 1	Leg 2	Total
	(mW)	(mW)		(%)	(%)	(%)
Diode	20	18	90	10.5	37	47.5
YAG	50	55	30	25.5	22	47.5

The output from each leg for both lasers has been set up in the configuration shown in Figure 4 to test the coherence of the output. The beams form each leg were approximately collimated and their interference resulted in a fringe pattern consisting of a set of concentric rings. The location of the one leg was changed to determine the coherence length of each laser. The diode laser was found in this manner to have a coherence length of approximately 4 cm, which slightly exceeds the manufacturers specification, (assuming control temperature to within a 0.1 °C). This should be enough to make holograms, although careful attention will have to be made in matching path lengths of the object and reference waves. The YAG laser has a rated coherence length of greater than 25 m, which could obviously not be confirmed with the simple set up used here. A path length difference of approximately one-half meter was, however, tested and the fringes were still quite visible, as would be expected.

Due to an accident during the system check out, one of the output fibers was broken and has had to be returned to the manufacturer for repair. The system is expected back within a week. The entire breadboard has been checked out and characterized and will be ready for use in making holograms upon return of the fiber optic system.

Experiments

Four experiment series have been performed to date. The first two experiments were for shaking down and testing the laboratory apparatus at MSFC. The third and fourth series were to produce actual TCHI data using the sucrose cell especially designed for for testing TCHI. The third series was run during the first week of March and the fourth series was run during the first week of July. In each of the last two series, the data has been recorded on VHS video tape for later analysis. That analysis is now underway. The following tables outline the content of the video tapes.

Series 3, March 1993

During this experiment series we selected temperature changes from the following:

dn/dt = $10^{-4}/^{o}C$ which produces

1. 6 fringes/^{o}C for HeNe.
2. 2.26 fringes/^{o}C for HeCd.

We found that the phase shifter had the following calibration:

The number of steps of the stepper motor driving the phase shift wedge for a 360 degrees phase shift was:

= 30,000 for blue
= 43,000 for red.

We ran approximately thirty experiments to include constant T and C at various values, then to include gradients in T and C. During this experiment series we became familiar with the operating characteristics of the cell. We experimented with methods to induce temperature and concentration gradients into the solution. The cell temperature is increased by raising the temperature of the top and bottom, independently, with gradients being introduced by observing before equilibrium is reached or by setting the top and bottom of the cell to different temperatures.

The following table provides the experiment values that correspond to the tapes that were produced. Each experiment recorded on tape includes five interferograms of the condition with an equal phase difference being introduced in each one.

Exp No	Condition	Top T	Bott T	Notes
1	Const T & C	22.01	22.13	Pure Water
2	Temp. Grad.	22.31	22.43	delta of .3 C
3	20 min. later			const. T
4	Raise T .3 C	22.60	22.71	t=10:40
5		22.90	23.00	10:59
6	Temp. Grad.	22.90	22.7	11:25
7	Fill cell to top	22.89	22.69	11:51
8		22.71	22.70	13:44

9	1/5000 sucrose			sucrose on bottom
10	stirred			
11	4/10000			
12				14:24
13	+3 to top and bot	23.00	23.00	
14		23.30	23.30	14:40
15		23.60	23.60	
16		23.3	23.3	
17	6/10000 sucrose	23.3	24.6	
18	4/10000 sucrose	22.74	22.98	Next day 13:05
19	6/10000 sucrose			
20	Const C 3/10000	23.75	24.02	Stir 14:02 data 14:12
21	Bad data			
22	Bad data			
23	Clean cell			Pure water
24	1/500 sucrose	23.10	23.21	
25		23.09	23.21	
26		24.07	23.21	T drops to 23.8 in meas.17:31
27		23.65	23.21	
28		25.07	23.21	18:12 Heaters shut off
29				13:25
30		24.02	23.30	13:32 dropped .3 during meas.
31		24.02	22.30	Faster stepping 14:04

From the constant T and C experiments we can determine the values of dn/dT and dn/dC required to solve the equations for T and C after we determine the refractive index.

Experiment Series 4, July 1993

Our objective during this series was to take the highest quality data possible and to add a combined temperature and concentration gradient. The following table provides the conditions for the experiment series.

Exp No	Condition	Top T	Bott T	Notes
1				
2	1/1000	21.32	21.26	Constant C
3		21.82	21.72	
4		21.32	21.26	
5	1/500 suc.rep.2cc	21.32	21.26	
		21.51	21.43	
6	1/500 suc rep 2cc	22.51	22.43	next day
5b				Cleaned windows
6b				
6c	Repeat cond. 6			Rem/ret cell
7a	Pure water			Ref. wave generator
7b	dup 7a			
8	Conc. grad. Const T	21.26	50.72	mix with 7a,Top T faulty
9	Same as 8			Hol 8

We learned by experience that we cannot add water taken from a different room without adding a T gradient that delays the experiment.

To reduce the video data to the end result required the development of image processing software that is still not fully completed. However, enough data has been reduced to lead to the following conclusions.

1. To achieve the highest possible sensitivity requires that fewer steps must be used to produce the interferogram that is ultimately analyzed.

2. The required sensitivity to extract temperature and concentration for the interferograms is achievable.

3. Optical noise in the images limits overall accuracy of the data. Procedures are needed to reduce some of the noise effects.

4. The blue image is approximately 10 percent smaller than the red image, a result for which we have no concrete explanation.

Image Analysis

- Data Acquisition

The data was originally acquired using a VHS recorder. It was copied and sent to the MetroLaser laboratory for analysis. When received, the video data had very poor frame-to-frame synchronization which prevented proper digitization. A time base corrector was inserted between the play back VCR and the Imaging Technology Incorporated OFG frame grabber which was used for the digitization. This produced data that was adequate for frame grabbing, although the data was quite noisy. The noise was probably due to the large number of data transfers, seven in all. They are original camera and recorder, the playback unit and recorder for copying, the playback unit and time base corrector for digitization, and finally the digitizer. For future testing, it is recommended that the data be digitized directly when taken, which will reduce the acquisition to two processes involving only the camera and digitizer.

It was also observed that the red and blue images were of different sizes. This result was not expected and we do not have a complete explanation for it at the present time. To correct this problem, the blue images will be "warped" using a six degrees of freedom algorithm. This will correct for x and y scaling, x and y translation, and skewing. Three points are required for this process. The points used were water spots or other artifacts on the surface of the cell. In the future it is recommended that permanent fiducials be place on the cell. This will allow for easy alignment and warping.

- Software Analysis

Software to process, display, and archive the data derived from the holographic interferograms is in the process of being developed. It will include software to analyze the holographic fringe data, which was gathered from the video digitization of four image frames that were phase stepped equally from each other. After the data is analyzed, the results will be displayed on a DOS PC with a VGA compatible video adapter. This data will be stored in a file which may be read by high level programming languages such as C or basic. The displayed data will also be able to be stored in a format so it may be graphically inserted into Windows applications.

PHASE SHIFT INTERFEROMETRY EQUATIONS

The theory for phase shift interferometry is well covered in various textbooks, and a variety of algorithms have been discussed so far. Dr. Vickram has analyzed a new algorithm developed during this program which will be published in Applied Optics. For completeness here, we present some of the equations used in the data reduction. The intensity of a point, I (x,y), in the interferogram can be described by the following:

$$I = I_A(x,y) + I_B(x,y) + 2\sqrt{I_A(x,y)I_B(x,y)}\cos\phi \qquad (1)$$

Where I_A and I_B are the intensities at any point of reconstructed image of the hologram and the actual image, and ϕ is the phase angle between them. Since the intensity I is the only variable measured from the video frame grabbing, and there are three unknowns two more equations are required. These may be generated by phase stepping one of the images by an amount θ. This was accomplished by placing a thin glass plate in one of the reference beams and tilting it through a small angle. The two additional equations are:

$$I_2 = I_A(x,y) + I_B(x,y) + 2\sqrt{I_A(x,y)I_B(x,y)}\cos(\phi + \theta) \qquad (2)$$

$$I_3 = I_A(x,y) + I_B(x,y) + 2\sqrt{I_A(x,y)I_B(x,y)}\cos(\phi + 2\theta) \qquad (3)$$

If the angle θ is not known, a fourth equation similar to equations 2 and 3 may be generated with a 3θ phase step. This set of simultaneous equations may then be solved at all points in the interferogram. The solution will produce a map of the optical path differences(OPD) modulo 2π.

The 2π ambiguity is then resolved through an unwrapping process. The results will be in the form of a file with the OPDs normalized to an eight bit value. A header in the file will have scaling information. Data from this file will be convolved with information relating the OPD to the temperature and concentration. Cross sections and area maps will then be displayed. These displays can then be inserted into a Windows applications.

Several programs are being written to analyze the holographic data. They may be classified into three groups:

- Those used to process the raw holographic data.
- Those used to display the results.
- Those used to store and transfer the results.

Although there may be a series of several programs required to analyze the data, they may be run by a simple single DOS batch program.

A program to preprocess the images through the use of a low pass filter has been completed. This program is necessary to reduce the noise from all the data transfers. In addition to reducing these errors which usually occur from electrical noise, this program will also reduce the maximum fringe density which may be processed. Since the fringe density of anticipated interferograms is low, low pass filtering should not be a problem. A simple 5 by 5 moving kernel and uniformly weighted average was used. More sophisticated filters would have adversely effected the fiducial.

A program to solve the set of simultaneous equations has been completed. It uses four frames of data which requires only that the phase steps be of equal but not necessarily known size. The unwrapping program is in the process of debugging and making it user friendly. No work has occurred on the program to convolve the OPDs to temperature and concentration.

A program to display cross sections has been written. It allows the user to move the cross sectional lines and change from horizontal to vertical sections. A program to generate the area maps has not been started but a program to display these maps is completed.

A program to convert the images to tiff files is complete. It may be used to insert raw image data, phase mapped data, area map data, and with some modifications the species mapped data into Windows applications. All of these data forms may be further operated upon using high level languages.

No work has been started to insert cross sectional displays into Windows.

WORK PLANNED FOR NEXT PERIOD

The software for the data analysis will be completed and implemented to reduce a representative sample of the video data taken in experiment series 3 and 4.

Another experiment series will be performed to implement what has been learned from previous experiments. We will attempt to take data that has a higher S/N by digitizing the data directly into a frame grabber without first recording it on video tape. Explanation of the different image size as a function of wavelength will be sought.

The breadboard will be reassembled for the production and evaluation of two color holograms.

A general paper will be planned for Applied Optics to cover our conclusions and techniques developed so far.

STATUS

As of the payroll ending 10 September 1993, $112,618 has been expended in the project, leaving $67,596 to cover estimated costs through 31 July 1994.